A tamarisk habitat suitability map for the continental United States

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This paper presents a national-scale map of habitat suitability for tamarisk (*Tamarix* spp, salt cedar), a high-priority invasive species. We successfully integrate satellite data and tens of thousands of field sampling points through logistic regression modeling to create a habitat suitability map that is 90% accurate. This interagency effort uses field data collected and coordinated through the US Geological Survey and nation-wide environmental data layers derived from NASA's MODerate Resolution Imaging Spectroradiometer (MODIS). We demonstrate the use of the map by ranking the 48 continental US states (and the District of Columbia) based on their absolute, as well as proportional, areas of "highly likely" and "moderately likely" habitat for *Tamarix*. The interagency effort and modeling approach presented here could be used to map other harmful species, in the US and globally.

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Tamarisk (*Tamarix* spp, salt cedar) is an Asian tree/shrub species which is invading riparian zones in the United States (Christensen 1962; Robinson 1965). It alters stream hydrology, increases soil salinity, and degrades habitats for native species. There are substantial costs associated with the eradication or control of tamarisk, with implications for water salvage, wildlife use, and riparian restoration (Shafroth *et al.* 2005). Furthermore, many organizations, from federal agencies to grass-roots citizen coalitions, are concerned with tamarisk invasion. For example, the Secretaries of the Interior and Agriculture have called for a cooperative initiative to control invasive tamarisk (USDoI 2005), highlighting a national interest in setting priorities for tamarisk-related control and restoration efforts. These efforts, in turn, require geospatial information on tamarisk distribution, abundance, and suitable habitat at a national scale.

Here we present a map of tamarisk habitat suitability throughout the continental US. This work builds on recent analysis in the western US, showing the abundance of tamarisk in that region (Friedman *et al.* 2005). Our model, based on positive field locations and absence locations, shows that many low- and mid-elevation waterways in western and central US are vulnerable to tamarisk invasion. The potential habitat for tamarisk goes well beyond areas where it already occurs. Along with providing current distribution data, this habitat map can help guide containment boundaries, identify priority areas for early detection and rapid response, and monitor control strategies and cost-effectiveness in different states. We consider this mapping effort to be a first approximation for mapping tamarisk habitat at the national level. It will be improved upon as more field data become available, additional continental-scale environmental data layers are constructed and incorporated into the model, and users provide feedback.

The habitat map was constructed by coupling field data with geospatial information derived from satellite imagery. The US Geological Survey (USGS) compiled field data indicating the presence or absence of tamarisk from over 40 datasets and covering 32 148 points. The field data provided sufficient information to both construct and test the model. Two-thirds of the data were used to construct the model and one-third was used to test the results. These data were coupled to remote sensing data from the National Aeronautics and Space Administration's (NASA) Earth Observing System through a logistic regression.

Previous studies have also used remote sensing datasets to predict invasive species. For example, Peterson (2005) estimated cover of invasive grasses using a modeling approach similar to that described here, but for a smaller area with higher resolution data. Several studies have shown a relationship between a remotely-sensed spectral response and tamarisk habitat, but again, these are for smaller areas using higher resolution satellite or airborne data (Everitt *et al.* 1989; Everitt *et al.* 1996; Everitt and DeLoach 1990). The novel aspect of the work presented here is its national scale.

The stepwise logistic regression modeling procedure provided an empirical method to relate field data points to environmental layers derived from remote-sensing data covering the contiguous US. Previous work showing the spectral–temporal signature of tamarisk (Everitt and

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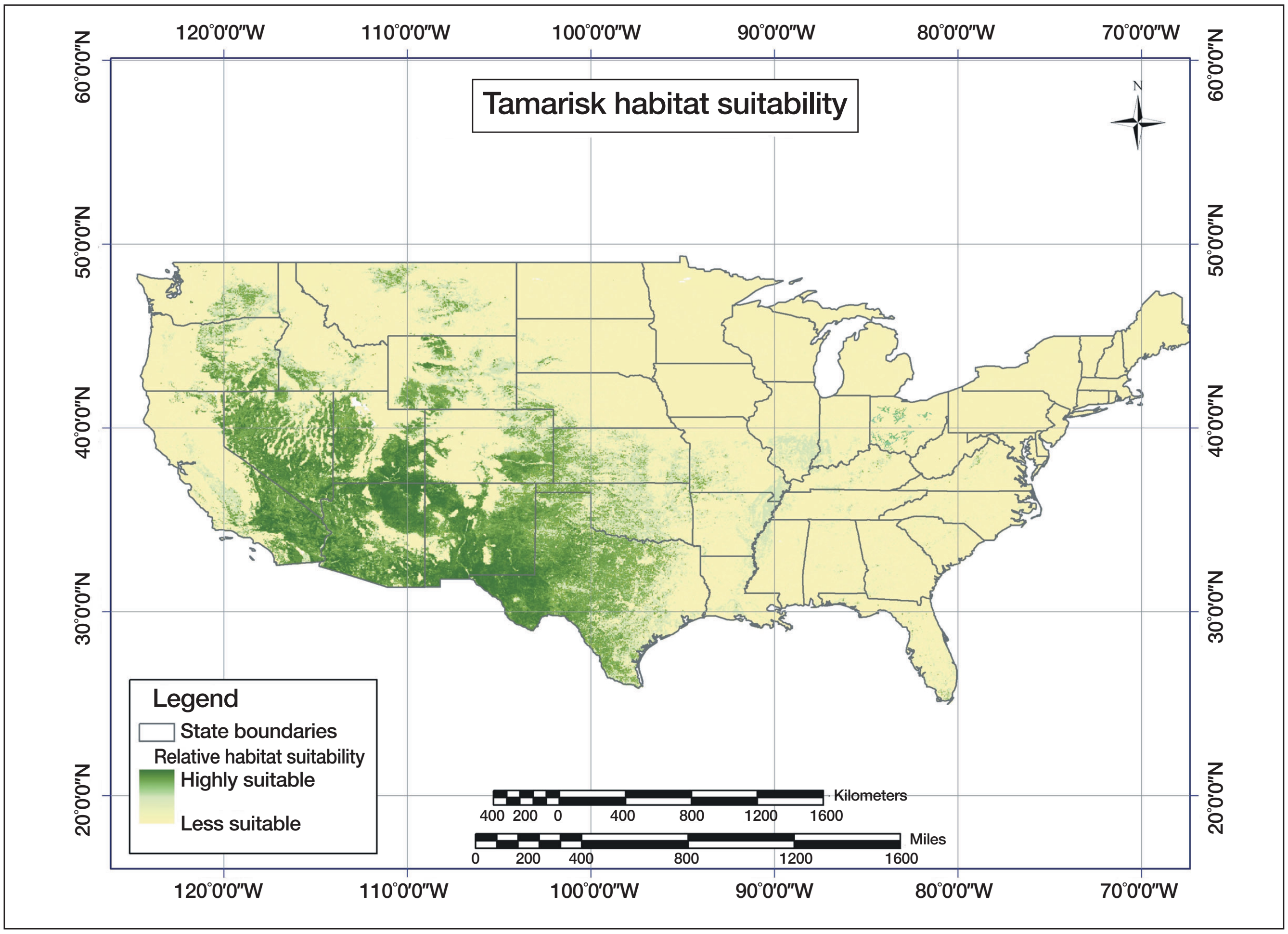

Figure 1. *Tamarisk habitat suitability map for the continental US.*

DeLoach 1990) led us to exploit the phenology observed in the time series of the MODerate Resolution Imaging Spectroradiometer (MODIS) vegetation index (Huete *et al.* 2002). The model is refined by incorporating land-cover type, also derived from MODIS data (Friedl *et al.* 2002). The stepwise procedure resulted in a highly predictive (90.1%), parsimonious model relating the presence of tamarisk with land-cover type and seasonal variability of vegetation indices.

The logistic regression approach uses the environmental layers to characterize the habitat of known tamarisk locations as well as those areas with no tamarisk. Areas throughout the continental US exhibiting land-cover and vegetation characteristics similar to locations where tamarisk was observed in the field are associated with a higher metric in the derived map. Areas exhibiting characteristics similar to locations where field data indicated the absence of tamarisk are associated with a lower metric on the map (Figure 1). This metric is then used to classify "highly likely" (areas in the 99th percentile of the map) and "moderately likely" (areas in the 90th percentile) habitat.

Suitable tamarisk habitat is highly variable among states. In Table 1, the two separate columns labeled "rank by fraction" refer to the proportion of either highly or moderately suitable habitat compared to the size of the state. The map and table imply that there is a much greater area of suitable habitat for tamarisk than is currently invaded. (There is no explicit map of all areas that have been invaded, but the number of presence points in Table 1 and the work of Friedman *et al.* [2005] provide an indication of our current understanding.) The Colorado and Rio Grande River basins have experienced heavy infestations, but large areas in the west and southwest are indicated as having suitable habitat for tamarisk and so may be in danger of invasion from adjacent populations. The location and extent of suitable habitat indicates that we may be early in the tamarisk invasion process, or that other factors not measured here are limiting tamarisk spread. Another concern is that hybrids of various tamarisk species may be able to adapt to a wide variety of new habitats on this continent (GISD 2005). Alternatively, strategic containment efforts using biological, chemical, and manual control methods, followed by careful restoration of native species, may slow the spread of tamarisk and associated invasive species. In any case, remote sensing, survey data, and predictive spatial models are important tools for developing efficient and effective containment strategies for non-native species over large areas.

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